CASE STUDY: SICK BUILDING SYNDROME IN A HUMID CLIMATE

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ABSTRACT

An indepth environmental investigation was conducted at a four-story building officing 1200 employees in Oklahoma. A preassessment and walkthrough of the facility revealed extensive ongoing renovations throughout the building. Renovations consisted of installations of new partitions, carpeting, celing tiles, and repainting. Management was receiving numerous complaints related to the indoor air quality from all parts of the building, particularly the unrenovated areas. The majority of employee complaints originated from the unrenovated second floor; in contrast, few complaints had been submitted from the finished fourth floor area. Due to the disparity in employee complaints from these two floors, the investigation focussed on a comparison of the air quality on the second and fourth floors.

The initial walkthrough revealed inordinate amounts of dust in the occupied space of the second floor. High humidity levels were measured throughout the building. Other potential problems -- i.e., poor lighting, job stress, poor air circulation, stuffy air, thermal discomfort, smokers in the area -- were also noted at this point. Questionnaires were made available to occupants on both floors to attain a better understanding of employee problems and assist in formulating an investigation plan. Collectively the nonspecificity of the responses tended to indicate building-related problems often described by the term "Sick Building Syndrome" (SBS). Based on the questionnaire responses, the walkthrough

and particulate emissions and possible inadequacies of the mechanical ventilation system in providing the necessary amount of outside air. Although the building investigation revealed few signs of biological contamination, problems of this nature are not uncommon in climates with high humidity. The potential for biological proliferation in buildings with excessive humidity are discussed in the paper.

The SBS causation was multifactorial and thus could not be attributed to a single etiologic factor. Temperature and humidity problems were partially attributed to the inadequate provision of chilled water (at a low enough temperature) to ensure proper tempering and dehumidification of the supply air. These periodic excursions in temperature and relative humidity were compounded by an associated reduction in outside air which exacerbated the situation. Other recommendations had to do with improving the filtration system, balancing of the air handling system, improving the ventilation efficiency, separation of smokers and nonsmokers, and the infusion of a fastidious cleaning and maintenance program combined with an adequate supply of fresh air per ASHRAE 62-89 specifications.

INTRODUCTION

Investigating indoor air quality (IAQ) problems presents a formidable challenge which, in some ways, is more difficult than evaluating industrial environments. Procedures conventionally used in industrial hygiene are often inappropriate for application in nonindustrial environments (1). More sensitive procedures are required, since comfort, occupant well-being, and general population susceptibiities are parameters that are presently unaddressed by occupational threshold limit values (TLV's). Increasing office worker awareness and the current shift to office-based, service-type employment has increased concerns about IAQ in offices. This new level of awareness and concern, in conjunction with a consensus among employees that an IAQ problem exists, can result in highly charged emotions that may only be escalated in the all-too-common situation of a series of "sick building" complaints in the absence of a specific identified cause. A consistent, solution-oriented approach that systematically excludes a continually narrowing range of possibilities was employed to investigate a case of "sick building syndrome". The method included an overall site assessment as follows: An opening conference, walkthrough survey, personal interviews, questionnaire evaluation, environmental monitoring, and heating, ventilation and air conditioning (HVAC) analysis.

BUILDING STUDY

conference served to provide a forum to discuss employee complaints, building HVAC mechanics, smoking policies, and ongoing renovations at the four-story office building. The investigated building was a four-story office building housing more than 1200 employees in Oklahoma. Completed in 1979, it would be considered energy efficient (with sealed windows) by current standards. No asbestos insulation was used in construction. There are approximately 64,000 ft^2 of floor area per floor with 400 employees per floor, the majority performing clerical type duties.

A *walkthrough* of the facility revealed the following points of interest:

> The office space on the four floors is basically an open plan concept with the use of partitions to provide individual offices and privacy. The building had been in a constant state of renovation for the past year. Renovations consisted of new carpeting, new partitions, furnishings, painting, and addition of new ceiling tile. The renovations had been completed one floor at a time by temporarily moving employees

during construction. At the time of the investigation, the fourth floor had been completely renovated and employees had been returned to their space for a period of at least six months. In contrast, the second floor had yet to begin renovations and was occupied during the investigation period. Other floors were in various stages of construction and preparation. Thus for reference purposes, observations were made as a function of fourth floor conditions compared to the second floor. Both floors had the same open space plan but differences in maintenance and general office layout were apparent. The arrangement of the partitions on the second floor were highly disordered as compared to the more orderly and accessible arrangement of the fourth floor. The disordered infusion of partitions into the occupied space on the second floor presented a confusing maze-like atmosphere for the occupants to endure combined with a challenging dilemma for cleaning operations with respect to carpets and dust on office equipment. A buildup of dust on furnishings of the second floor was apparent. Cleaning personnel admitted the difficulty in accessing all areas of the second floor due to the layout. Dust buildup was less apparent on the fourth floor, possibly due to the recent renovations in conjunction with the partition arrangement being much more structured and more easily accessed by cleaning personnel. Air supply diffusers on the second floor showed signs of particulate buildup, possibly indicating inefficient filtration of the conditioned air.

The HVAC system was designed to provide air to the space, on a constant air volume basis, by ducted supply (ceiling supply diffusers) and open plenum return (above the false ceiling) to a chase which returned the air to a specific air-handling unit, mixed with outside air, filtered, tempered and returned to the space. Three separate air-handling units served each floor. The air-handling units were located on the first floor with outside air intakes located near ground level approximately 30 yards from the parking lot. Filtration was provided by a combination 25% American Society of Heating, Refrigeration & Air-Conditioning Engineers (ASHRAE) dust spot efficient prefilter followed by 85% ASHRAE dust spot efficient bag filter. Outside air dampers were typically set to provide a minimum of 10% outside air, but due to ongoing renovations the system was not properly balanced on the second floor and had been only partially adjusted for the fourth floor. The air is tempered by the use of chilled water during hot ambient conditions and steam during cold weather. During the winter, steam humidification is introduced into the system to keep the relative humidity at an acceptable level. On the occasion of the walkthrough in March of 1989, the relative humidity within the occupied space was 75%. Investigators were informed that there was a temporary interruption of the chilled water received from the maintenance facility. In the meantime, chilled water was being received from another area at a higher temperature than normally provided. Due to the elevated temperature of the chilled water, the efficiency of the system to temper the air (normal supply air temperature is 60°F) and the dehumidifying capabilities of the cooling coils are effectively reduced, resulting in higher temperature and relative humidity of the supply air.

Total volatile organic compounds (VOC's) concentration was checked on the second and fourth floors of the building. An h-nu photoionizer was used to approximate VOC levels throughout the space. Measurements revealed low concentrations (< 1 mg/m^3) even in the newly renovated areas, indicating either effective ventilation preventing contaminant buildup and/or the selection of low-emission product materials in the renovation. Highest readings were recorded near the photocopier machines which were subsequently checked during the monitoring phase. Researchers commonly recommend an action level of 1.0 ppm total VOC as an indicator of indoor air quality problems (2). (1.0 ppm VOC is approximately 5 mg/m^3 total VOC assuming an average molecular weight of 100.)

Many ceiling tiles were displaced or dislodged on the second floor. This may enhance the problem of poor air circulation and result in short-circuiting and poor ventilation effectiveness which is already hampered due to the partition obstruction of air flow. Ceiling tiles were in place on the fourth floor.

General area lighting on the second floor was very uneven and poor in some areas as opposed to the uniform lighting on the fourth floor.

The smoking policy in the building was one of individual preference. The policy is basically a designated smoking area policy, whereby each employee has the option of designating his or her work space as nonsmoking. Some employees voiced concern with respect to the effectiveness of this policy in protecting nonsmokers' exposure.

The office building was occupied on a 24-hour basis with approximate time of shifts being 12:00 am to 8:00 am; 8:00 am to 4:00 pm; and 4:00 pm to 12:00 am. The heaviest work shift is the daytime 8:00 am to 4:00 pm period.

After further discussion with building management and employee representatives, it was decided that investigators should focus the study on a comparison of air quality on the unrenovated second floor and renovated fourth floor.

QUESTIONNAIRE EVALUATION

The next phase of investigation involved the distribution of questionnaires to employees to solicit their responses/concerns pertaining to their indoor environment. In May 1989, questionnaires were made available to employees on the second and fourth floors, collected, and then analyzed.

The questionnaire results are arranged with respect to each floor. Questionnaires from the *second floor* revealed the following:

The primary complaint of employees (82% of those responding) pertained to a lack of air circulation; specifically the air being stuffy.

Other complaints, in order of decreasing rank per employee response were:

presence of cigarette smoke (66%)
temperature too hot (49%)
dust in the air (40%)
temperature too cold (29%)
disturbing noises (24%)
noticeable odors (22%)
poor lighting (less than 5%)
outside fuel odors (less than 5%)
high humidity (less than 5%)

The majority of respondents stated that indoor air quality (IAQ) problems (such as those referred to above) occur on a daily basis and have always existed as long as they have worked in the building.

The principal health symptoms experienced by employees in order of decreasing rank per questionnaire responses were:

headache
runny nose
drowsiness
eye irritation
difficulty breathing
sinus problems
congestion
sneezing
nausea

(84% of the respondents reported symptoms clearing up within 1 hour after leaving work.)

The majority of employees performed clerical duties throughout the day.

While only a small percentage of respondents were smokers (11% of those turning in questionnaires were smokers), 78% of the respondents had complaints that others in their immediate area smoked and that very little attention was paid to no smoking signs displayed by individual employees in their respective area.

Questionnaires from the *fourth floor* revealed the following:

The primary complaint of employees (68% of those responding) pertained to thermal comfort; specifically the temperature being too hot.

Other complaints, in order of decreasing rank per employee response were:

lack of air circulation (stuffy) (56%)
presence of cigarette smoke (28%)
disturbing noises (23%)
temperature too cold (17%)
dust in air (17%)
temperature inconsistent (15%)
noticeable odors (8%)
humidity too high

The majority of respondents stated the IAQ problems occur on a daily basis and have always existed for as long as they have worked in the building.

The principal health symptoms experienced by employees in order of decreasing rank per questionnaire responses were:

headache
drowsiness
difficulty in breathing
stuffy nose
runny nose
sneezing

(76% of the respondents reported symptoms clearing up within 1 hour after leaving work.)

The majority of employees performed clerical duties throughout the day.

Few of the respondents were smokers, but approximately 50% complained of other smokers in their immediate area.

Reviewing the questionnaires received from the two floors, shows obvious similarities between the complaints and health effects observed. The percentage of complaints with respect to each complaint response was typically lower for the fourth floor as compared to the second. Thus, while the complaints from the two floors have much in common, there is an apparent reduction in severity of the complaints (i.e. dust in the air) on the fourth floor. Thermal discomfort, presence of cigarette smoke, and lack of air circulation were the primary perceived causes of problems on both floors. The health symptoms were also very congruent between the two floors. The non-specificity of the health symptoms reported (i.e. headaches, drowsiness, difficulty in breathing, etc.) are consistent with the complaints of thermal discomfort and stuffy air. Collectively, these responses tend to indicate building-related problems that have been described by the term "Sick Building Syndrome". The symptoms do not imply a clinically defined illness or disease, but rather a series of nonspecific complaints being voiced by employees as a function of their work environment. Such a set of general symptoms in the absence of an identified cause has been termed Sick Building Syndrome (3,4,5,6,7,8).

The National Institute for Occupational Safety and Health (NIOSH) has conducted close to 500 investigations of IAQ related complaints since the late 1970's, and have classified their evaluations by primary type of causative factor: inadequate ventilation (52%); contamination from inside the building (17%); contamination from outside the building (11%); microbiological contamination (5%); contamination from the building fabric (3%); and unknown (12%) (9). Other factors that may contribute to sick building syndrome include inadequate layout of work stations, insufficient lighting, overcrowded work space, ambient noise, and all factors related to working conditions and work relations. Numerous studies published indicate that inefficiency of the ventilation systems, as well as insufficient maintenance of HVAC components, are the main sources of problems (10).

Due to the nature of the health symptoms listed in the questionnaires and the number of employee complaints with respect to stuffy air, pervasive smoke in the air, dusty conditions and thermal discomfort, it was decided that the investigation should focus upon identification of and testing for sources of chemical and particulate emissions and possible inadequacies of the mechanical ventilation system in providing the necessary amount of outside air. Because there were no signs of water damage or other possible reservoirs for microbiological proliferation, accompanied with the lack of specific illnesses cited in the questionnaires, the investigation did not focus on biological contaminants. Although a minor degree of bioaerosol sampling was conducted to ensure that nothing was out of the ordinary. The environmental sampling to be conducted at the facility consisted of the following:

> Questionnaire distribution and evaluation; formaldehyde sampling; particulate sampling; bioaerosol sampling (consisting of nonviable and viable fungi spore sampling); carbon monoxide, carbon dioxide, temperature and relative humidity levels to be monitored over 12-hour periods on two separate days; dust mite sampling; general inspection of the HVAC system, filters, and fresh air intakes, and air circulation patterns; and general office illumination analysis.

ENVIRONMENTAL MONITORING, HVAC ANALYSIS, AND INTERPRETATION

BIOAEROSOL ANALYSIS

Bioaerosols are biological agents carried in the air as single particles or clusters of particles. Although this description includes viruses, bacteria, fungal spores, pollen, animal dander, protozoa, and biological toxins, the present investigation was limited to a consideration of only pollen, spores, and mites. In general most indoor bioaerosol problems result from outdoors. Spores and pollen are ubiquitous in the outdoor environment (11). Oklahoma has a tremendous floral diversity, and pollen from local sources is present in the atmosphere for at least ten months of the year from early February through November (12,13). In addition, pollen also occurs in the atmosphere in December and January due to the prevailing southerly winds transporting pollen from southern Oklahoma and Texas (14).

A mild continental climate with long hot summers and cool winters was representative of the study region; both spring and fall are normally wet with mild temperatures and high humidity. In addition, prevailing winds are southerly bringing Gulf Coast humidity to the area any time of the year. The ambient climate is ideal for fungal growth, and fungal spores, commonly called mold spores, are also normal components of the outdoor air. They are present in the atmosphere virtually throughout the year except for the few days when the ground may be covered with ice and snow. The spores are discharged from fungi growing as saprophytes (existing on dead or decaying organic matter in the soil or anywhere in the environment) or parasites (infecting living tissue - most are plant pathogens). Many species are found as leaf surface microorganisms where they exist on organic matter produced by the plant.

Any time that outdoor air is introduced indoors, bioaerosols (pollen and spores) will also be introduced (15). While many particulates will eventually settle out or even be filtered out, fungal spores can be amplified indoors. While the fungal spores are a normal component of the outdoor air, indoors they are considered contaminants because of the amplification potential. Many common substrates serve as nutrient sources for saprophytic and/or pathogenic fungi and thus allow for growth and continued spore formation indoors. Although the list of suitable substrates is extensive, the most familiar include carpets, upholstered furniture, showers and other bathroom fixtures, humidifiers, potted plants, and the soil surrounding the plants. Any time moisture or high humidity is available, spores can germinate and fungi can grow and produce thousands of new spores utilizing any organic material available in these sites. In buildings with central HVAC systems, properly maintained in-duct filters should remove many of the spores present. Many instances, however, are known where the HVAC system itself served as an amplification and dissemination site for fungal spores. In these cases fungi have been found growing on air filters as well as in the ducts. Normally this can be prevented by routine maintenance.

When sick building syndrome and/or building-related illness is suspected, public or private agencies often investigate the facility and conduct chemical and/or biological sampling (16). In biological sampling for fungi, reports often indicate the number of colony forming units per cubic meter of air or the number of spores per cubic meter. Some studies will provide further analysis by comparing the indoor data to the outdoor data, while other studies compare different areas within the facility (16,17).

There are as yet no guidelines for bioaerosols. However, a level of 1000 Colony Forming Units (CFU) per cubic meter for viable microorganisms in indoor air has been suggested as a guideline in the literature (18). This recommended limit was never intended to imply that a viable bioaerosol concentration of 1000 CFU/m^3 is a permissible exposure or action level or a threshold limit value. A bioaerosol concentration of 1000 CFU/m^3 was intended merely as a crude indicator for what might be considered as atypical for an office environment. No health relationship was meant or should be implied. A recent report of the American Conference of Governmental Industrial Hygienists (ACGIH) Committee on Bioaerosols suggests a more reasonable guideline that indoor levels of saprophytic bioaerosols should be less than one-third of outdoor levels (19).

In suitable hosts, bioaerosols are capable of eliciting diseases that may be infectious, allergenic, or toxigenic (15,16). These diseases vary with their severity and rate of attack. Risks to the host depend on the concentration of the bioaerosol, the particle size, and its virulence or antigenicity. Risk also depends on the individual susceptibility of the host. In recent years a great deal of attention has been focussed on the increased risk of opportunistic fungal infections in immunocompromised patients.

These conditions may be acute or chronic. Legionaire's disease and related Pontiac fever are infectious diseases in which symptoms appear quickly, while hypersensitivity pneumonitis is a disease that develops over a long period of time. Many types of pollen and many fungal spores (possibly all) are allergenic, capable of causing allergic responses such as asthma or rhinitis in susceptible individuals. A small group of fungal spores are human pathogens. While many human pathogens just cause mild or annoying conditions, such as athlete's foot and ringworm, other human pathogens can cause severe and debilitating diseases (20). Spores of some of these fungi are well known to be disseminated in the air. In addition, many common saprophytes are capable of causing serious human infections in immune compromised individuals and in individuals taking certain types of medications.

Biological sampling was conducted on October 23 and December 13, 1989. Sampling consisted of air analysis for total viable and nonviable allergenic fungal flora present in specific areas on the second and fourth floors. Due to the absence of an identified infectious disease in the building complaints, random bioaerosol sampling of allergenic saprophytic fungi was conducted on both floors.

The bioaerosol sampling on both floors for viable microorganisms through use of the Andersen sampler revealed very low levels of fungi and bacteria; all indoor samples were well below any suggested guideines of concern and reflected a very small fraction of outdoor levels (400 CFU/m^3). The highest level found indoors was 27 CFU/m^3 on the second floor. Based on these samples it is unlikely that the interior is seriously contaminated with fungi since levels were markedly lower than those outdoors, and none of the fungi recovered are unusual in outside air.

The bioaerosol sampling on both floors for total viable and nonviable spores through use of the Burkard samplers basically confirmed the findings of the Andersen sampling which showed low microbiological airborne activity. Smut spores and basidiospores were common at several indoor locations; such spores do not proliferate on any indoor substrates and thus must be introduced from outdoors. The overall low concentrations and the outdoor spore types indicate that there is little or no amplification occurring indoors.

One of the most strongly allergenic materials found indoors in homes is house dust that is contaminated with the fecal pellets of dust mites. Dust mites are arachnids (members of the spider family) whose survival depends upon the consumption of skin scales of other animals. Dust mite allergen is hypothesized to be one of the most important causes of asthma in North America, as well as the major cause of common inhalant allergies. Dust mites survive in highly humid environments; thus there is a strong dependence on indoor relative humidity levels and observed dust mite populations. Dust mite samples were taken October 23, 1989 (relative humidity in building, 45%). The six samples taken on the two floors showed no sign of dust mites. Typically dust mites have not been shown to be a problem in office buildings as is the case in residential dwellings, but during the the summer months combined with high humidity within the occupied space, dust mites may proliferate.

PARTICULATE SAMPLING

Due to the high number of complaints with respect to the presence of dust and particulate matter in the air, sampling was conducted to check total airborne particulate concentration. Dust and particulate are often generated in office buildings owing to the high level of paper use and movement. The hazard from airborne particles varies with their physical, chemical, and/or biological properties. These properties will determine the fate of the particles and their interactions with the host after they are deposited. Particle size is an important factor for evaluating deposition in the lung and transport in the environment. Of principal concern are the particulates below 5 microns in size since they are respirable and remain suspended in the atmosphere for an extended period of time.

The hygienic standard for particulate is 10 mg/m^3. The Occupational Safety and Health Administration (OSHA) limits on respirable dust (below 5 microns in size) is 5 mg/m^3. According to the Environmental Protection Agency's (EPA) National Ambient Air Quality Standards, levels of total suspended particulates less than 10 microns in acceptable outdoor air should not exceed a yearly average of 50 $\mu g/m^3$. This 50 $\mu g/m^3$ level is more than two orders of magnitude less than the hygienic standards for total nuisance dust, but is currently being recommended by IAQ investigators as a standard for indoor environments primarily to control discomfort and annoyance from cigarette smoke (21). Typical concentrations of total particulates in an office environment range from 30-40 $\mu g/m^3$ (22). The Oklahoma secondary standard for total dust concentrations of ambient air is 70 $\mu g/m^3$.

Fifteen general area samples were taken over the 8:00 am to 4:00 pm work period on each of the second and fourth floors and were analyzed gravimetrically for total suspended particulates (TSP). In all instances the reported dust concentrations on the second and fourth floors were far below the hygienic standard of 10 mg/m^3. Concentrations on the second floor ranged from a value of none detected up to a maximum of 81 $\mu g/m^3$. Most of the higher values on the second floor were in the 30-50 $\mu g/m^3$ range. Such values are not out of the ordinary and do not constitute cause for concern. Concentrations on the fourth floor ranged from a value of none detected (6 of the 15 samples taken on this floor had no detectable amount of dust collected) up to a maximum of 51 $\mu g/m^3$. Most of the higher values recorded on this floor were in the 20-35 $\mu g/m^3$ range. These values are well below any cause for concern. The values on the fourth floor were notably lower than those from the second floor which is consistent with the higher number of reported dust complaints on the questionnaires. This may be due to the lack of cleaning maintenance in the unrenovated section of the second floor, combined with the ongoing construction throughout the floor which may be stirring up more dust. It must also be noted that the highest dust time weighted average reported on the second floor (81 $\mu g/m^3$) was measured in an area occupied by a higher population of smokers which may have contributed to the elevated particulate concentrations. Lower reported dust values in the renovated areas appear to lend credence to the hypothesis that these areas provide an improved, cleaner environment that is easier to maintain as opposed to the older unstructured layout.

Observation of the air supply diffusers on the second floor revealed significant amounts of dirt buildup on many of the ceiling units. The material appeared to be carbon-like material which would indicate a possible by-product of a combustion process. Material from several supply diffusers was collected and analyzed. Lab results indicated the buildup was not a carbon residue, but rather a combination of dirt and cellulose. This is not uncommon in an office area where much paperwork is handled and general human activity is continuous. The more important aspect of the collected dust on the supply diffusers was the question of why this fairly coarse material was not being properly filtered out upstream of the supply ducts.

Upon close examination of air handlers supplying air to the second and fourth floors, it was found that the housing access door seals on many of the systems had deteriorated or were coming loose from sheetmetal surfaces. This condition allows unfiltered or contaminated air from mechanical rooms to infiltrate the systems on the downstream side of the filters. Mechanical rooms that are not cleaned regularly or are used for storage are sources for contamination that, when allowed to infiltrate a system, can contribute to poor indoor air quality.

It was also noted that the filter tracks did not have seals nor did the final filters themselves have seals to prevent unfiltered air bypass. Seal integrity is of utmost importance in any system where the use of high efficiency filters are employed. In the case of seal failure or lack of seals, air will seek the path of least resistance and will actually decrease the filtering efficiency substantially. As filters load and pressure drop across the filter bank increases, leakage velocities also increase dramatically, allowing small and sub-micron particulate to bypass the filters. Another point of concern was that the spacers between the filters did not fit well, and in one case the space was missing, allowing the filters to spread out and leave numerous gaps between the filters.

Although there was no evidence of dust and dirt caking excessively on the inside of ducts and equipment, dust could be seen and felt as access panels were opened with the system in operation. A portable solid state Met One laser particle counter was used to obtain counts with fairly large readings recorded in the sub-micron range downstream of the filters. However, these readings could not be used in determining filter performance due to inadequate access on the immediate downstream side of the filter banks and due to excessive air bypass because of the lack of seal integrity. It was noted, by use of the particle counter, that whenever the bag filters were touched or bumped there was a very large amount of particulate shedding or migration from the bags.

SMOKING DISCUSSION
(with respect to employee complaints)

Investigators felt compelled to address this topic due to the high percentage of employee complaints disclosed in the questionnaires with respect to the presence of pervasive cigarette smoke in the air. Indoor exposure of nonsmokers to tobacco smoke, termed either environmental tobacco smoke (ETS) or passive smoking, has been linked to long and short-term health effects; as a consequence, a considerable number of studies have focused upon the presence of ETS in an enclosed environment (18).

Design ventilation rates in North America are set by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), currently under ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality" (23). This standard provides for recommended amounts of ventilation based upon occupancy. The ASHRAE Standard specifies a typical design occupancy of seven workers per 1000 ft^2 of office space (approximately the same occupant density present within the building), and provides for 20 cubic feet of outdoor ventilation air per minute per occupant in offices *with a moderate amount of smoking* and higher rates of ventilation in spaces with an intensive amount of smoking. This is called the *ventilation rate procedure*. The standard is not specifically designed to limit human health risk from ETS.

The smoking policy of "designated smoking offices" in the building has been previously referred to in this report. Numerous research reports on the subject of ETS have concluded that simple separation of smokers and nonsmokers within the same airspace may reduce, but does not eliminate, exposure of nonsmokers to ETS. Recirculation of tobacco smoke gas constituents in central ventilation systems is an important source of exposure of nonsmokers to ETS in office buildings. "Central air circulation systems and people movement increase the nicotine level throughout all rooms of a centrally ventilated building, regardless of the smoking policies of an individual office complex" according to Whitaker and Jennings (24). The EPA concludes in its 1989 Report to Congress on Indoor Air Quality, "ETS is best controlled by smoking bans, or by restricting smoking to rooms that are depressurized relative to the nonsmoking part of the building and directly exhausted to the outside" (25).

To date, no single satisfactory method is available to measure the amount of cigarette smoke present in a work space. Carbon monoxide and formaldehyde levels were monitored throughout the second and fourth floors to attempt to approximate the contributions of these pollutants as a function of ETS. Other interior and exterior building sources of these pollutants are also present and shall be discussed. Both carbon monoxide and formaldehyde are considered to be hazardous contributors to the detriment of IAQ and represent major gas phase constituents of ETS in indoor air. Researchers have documented the numerical similarities between the concentration of carbon monoxide contained in automobile exhaust and that contained in mainstream cigarette smoke. Historically, carbon monoxide has been a widely used chemical marker for monitoring ETS exposure (26).

FORMALDEHYDE SAMPLING

Formaldehyde is an ubiquitous indoor air contaminant that is a suspected human carcinogen and a potent eye, upper respiratory, and skin irritant. Sources of formaldehyde include wood products, furnishings, insulation, tobacco smoke, partitions, ceiling panels, cosmetics, textiles, upholstery fabric, carpeting, fiberglass products, carbonless copy paper and other paper products (27).

Eight general area samples were taken on the second floor, while six samplers were placed on the fourth floor. Formaldehyde concentrations were monitored by means of passive bubbler diffusion samplers providing a time integrated measurement. The results indicate very low levels recorded in all cases. Concentrations ranged from .009 parts per million (ppm) up to a high of .039 ppm. There were no significant differences in levels observed on both floors. It is interesting to note that the highest level recorded (.039 ppm) was on the second floor at an area where there was a higher number of smokers as compared to other spaces. These results tend to concur with the total particulate sample readings that revealed highest concentrations of particulates in this same area. These elevated levels may be a function of the higher density of smokers. In both measurements (particulate and formaldehyde) in this area it is important to understand that while these readings were above others, they are still far below any hygienic standards for these pollutants.

The hygienic standard for formaldehyde is currently set by OSHA at 1 ppm over an 8-hour time weighted average. Normal indoor concentrations for formaldehyde are in the 0-0.1 ppm range. The World Health Organization and ACGIH have stated that concentrations greater than 0.10 ppm are of some concern, but there are no current standards enforcing that level (23). Here again, the measured formaldehyde levels on the second and fourth floors as a function of tobacco smoke, paper products, building materials, and other various sources are well below any levels of concern and/or any mandated limits.

CARBON MONOXIDE SAMPLING

Carbon monoxide is a colorless, odorless, tasteless gas that is slightly soluble in water and slightly lighter than air. It is an asphyxiant for which the mechanism of action is an avid binding to hemoglobin in blood. Its affinity for hemoglobin is about 210 to 250 times that of oxygen, thereby interfering with oxygen transport to tissues and resulting in tissue hypoxia. The health effects of low levels of CO exposure (carboxy-hemoglobin content $< 3\%$) are controversial and can be manifested as symptoms of headache, nausea, breathlessness, dizziness, and fatigue. At higher levels of exposure severe health symptoms may be manifested such as visual disturbances, cyanosis, mental confusion, angina, coma, and death (28).

Major sources of carbon monoxide in occupied spaces may include infiltrated exhaust from automobiles, parking lots and attached garages, ice resurfacers, propane refrigerators, furnaces, kerosene heaters, tobacco smoke (ETS), and other combustion processes.

Concentrations of carbon monoxide within second and fourth floors were monitored periodically throughout the work day (by means of a Miran 1-B infrared spectrophotometer) to obtain the diurnal variations in the CO levels and to ascertain whether or not the exposures were within an acceptable range. Data was taken on two separate days (September 14 and December 11, 1989) to determine if there were possibly any seasonal fluctuations as a function of changing HVAC conditions.

Reported concentrations within the occupied space varied from a low of 1.2 ppm up to 7.0 ppm (in a heavily concentrated area of smoking at the time of the sample). Representative data taken on September 14, 1989 are presented in Table 1. Generally, the levels on the second floor were slightly higher than those of the fourth floor, but these differences were not significant. All recorded levels were well below OSHA's newly revised time weighted average limit for carbon monoxide (over an 8-hour time frame) of 35 ppm. For informational purposes, the Federal EPA National Ambient Air Quality Standard for carbon monoxide is 9 ppm over an 8-hour exposure. (The EPA's air quality standards apply only to ambient concentrations and not to the work site.)

The World Health Organization has stated that concentrations of carbon monoxide below 9 ppm are of limited or no concern (23). The EPA has reported a mean value for office space carbon monoxide levels to be 3.59 ppm in a study of office buildings throughout the U.S. (28). Based on the above standards and information, carbon monoxide concentrations within the occupied space are well within established limits and are typical of office exposures.

The fluctuations in CO levels throughout the work day were consistent with what one would expect based on peak population densities within the work space along with peak times of automobile activity outside of the building. The outside air intakes for the building are located on the west side of the facility facing the parking lot. The intakes are below ground level within an enclosed sunken area that is open at the top for allowance of air flow. A primary source of CO in buildings can be due to infiltration of automobile exhaust from nearby garages and/or parking lots. Carbon monoxide concentrations within the building appeared to track outside fluctuations in CO. Outdoor levels were typically recorded to be highest at times of shift breaks as employees drove to or from work. Because of the fact that normal filtration systems have no removal efficiency with respect to CO, these times correlated well with the highest CO levels found within the occupied space. The data also reveals that the lowest CO concentrations are recorded at the end of the day after the shift change has occurred when the lowest occupant density is present within the space. The fact that the indoor CO concentrations follow such a trend provides an indication that adequate outside air is being introduced to reduce pollutant buildup in the building.

Carbon monoxide levels were moderately elevated in areas where smokers were concentrated, but it must be reiterated that the levels recorded are typical for such space and are not considered to be cause for alarm.

HVAC ANALYSIS

This phase of investigation basically focused on determining whether or not an adequate amount of fresh air was being provided to the work space to reduce buildup of contaminants. ASHRAE's Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality" is acknowledged by industry professionals as the primary standard that should be followed to provide for adequate ventilation in enclosed commercial spaces (23). The newly adopted standard recommends a minimum of 20 cfm of outside air per person within the occupied space based on an occupant density of 7 workers per 1000 ft^2 of office space. Because of the significance of the ASHRAE standard, and the previously discussed NIOSH findings with respect to inadequate ventilation, this phase of the building analysis was considered to be an integral part of the study. It must also be noted, from the questionnaire analysis, that stuffy air was listed as one of the primary complaints by respondents on both second and fourth floors.

A method which is gaining popularity, and which is currently used by NIOSH for evaluating the adequacy of ventilation to an area, is the measurement of carbon dioxide (CO_2) concentrations. Humans expire significant quantities of CO_2. The higher the CO_2 levels inside a building, the poorer the overall ventilation. The NIOSH guideline for carbon dioxide is as follows:

"Carbon dioxide is a normal constituent of exhaled breath and, if monitored, can be used as a screening technique to evaluate whether adequate quantities of fresh outdoor air are being introduced into a building work area. The outdoor, ambient concentration of carbon dioxide is usually 250-350 ppm. Usually the carbon dioxide is higher than outside, even in buildings with few complaints about indoor air quality. However, if indoor carbon dioxide concentrations are more than 1,000 ppm (three to four times the outside level), there is probably a problem of inadequate ventilation. In such situations, complaints about headaches, fatigue, and eye and throat irritation are frequently found to be prevalent. The carbon dioxide concentration itself is not responsible for the complaints. However, a high concentration of carbon dioxide may indicate that other contaminants in the building may also be increased and could be responsible for occupant complaints. If carbon dioxide concentrations are maintained below 600 ppm, with comfortable temperature and humidity levels, complaints about air quality should be minimal. If carbon dioxide levels are greater than 1,000 ppm, widespread complaints may occur and thus 1,000 ppm should be used as the upper limit guidelines." (1).

Carbon dioxide measurements provide an expedient method of verifying outside makeup air supply rates and air distribution. Carbon dioxide monitoring should be thorough enough to note variations, both by time and by location. Peak values of CO_2, for instance, typically occur in midafternoon. If it can be determined that the living, breathing occupants are the only source of CO_2 within the occupied space (the case in this investigation), then the resulting CO_2 concentrations can provide a measure of how well the ventilation system is diluting and removing air contaminants generated within the building. If the CO_2 is not being effectively removed and its concentration is building up, then similar conclusions can be made about other components of the indoor air. Carbon dioxide levels found in offices with outside makeup air supply rates at or above the ASHRAE guideline of 20 cfm of outside air per person and good air distribution should be below 700 ppm. Most times the levels are between 450 and 600 ppm. Levels elevated noticeably above 700 ppm have been found to represent problems in the HVAC system (29).

Carbon dioxide levels were monitored (through use of the Miran 1-B) on the second and fourth floors of the building for 12-hour periods on two separate days (September 14 and December 11, 1989) to evaluate the HVAC system with respect to seasonal variations. Outside temperature on September 14 was approximately 61°F while on December 11 it was 20°F. Sampling consisted of a series of measurements beginning prior to arrival of the 8:00 am work shift. This was done to obtain a baseline CO_2 level before the highest density of occupants entered the building. (NOTE: Employees were present to some extent on a 24-hour basis, but the lowest density of people in the building concurred with the 5:00 pm to 8:00 am evening and early morning work shifts.) Baseline samples were taken at all selected locations on each floor. Eight sites were checked on the second floor, along with seven sites on the fourth floor. During the day representative samples were taken at all sampling locations.

Representative data taken on September 14, 1989 are presented in Table 2. Initial readings in the building (baseline samples) were always somewhat elevated above outdoor levels due to the presence of people within the building at all times; but testing revealed the lowest CO_2 levels would concur with these times of lowest occupant density; before 8:00 am and after 5:00 pm. During the work day there were some rises and falls depending on occupant activity. The rises in CO_2 throughout the day were more apparent on the second floor as compared to the fourth floor readings. Levels on the second floor would steadily increase during the day with the highest readings observed during the 3:00-5:00 pm time period. Levels at several second floor locations during this time period were in excess of 800 ppm CO_2, indicating possible shortcomings of the HVAC system as previously discussed. Such a buildup of CO_2 during the work day, with a subsequent decrease after employees leave, is indicative of a situation whereby over a 24-hour time span the air intake is sufficient, but may not be sufficient during the hours the building is occupied.

Contrary to the second floor, there were only minor fluctuations of CO_2 levels on the fourth floor. Concentrations on this floor were typically higher when the building was occupied but these increases were not as significant as those observed on the second floor. Concentrations did not build to a marked extent on this floor and never approached 800 ppm (highest value recorded on the fourth floor was 756 ppm). These results suggest that fresh air intake was sufficient for the fourth floor (during the two days of testing). It is also important to note that while CO_2 levels on the second floor were somewhat elevated, on these two days of testing the measurements never exceeded the ASHRAE/NIOSH guideline of 1000 ppm.

To facilitate an approximate method for comparison with the ASHRAE recommended outside air provision of 20 cfm per person, the next step in the investigation of the HVAC system was to attempt to quantify the amount of outside air being provided by means of appropriate carbon dioxide measurements. The specifics of converting CO_2 concentrations to quantities of outside air delivered are presented in the ASHRAE Handbook of Fundamentals, and were recently reviewed in the New Jersey "Proposed Standards for Indoor Air Quality" (prepared by the NJ Public Employees Occupational Safety and Health Program) (30). Of particular interest for this study is the use of the "Three Point CO_2 Method" and "One Air Flow Method." For the "Three Point CO_2 Method", three measurements of carbon dioxide in different parts of a ventilation system and a mathematical formula are used to calculate the percent of outdoor air in the room supply air. In addition, one air flow rate determination at a specified part of the HVAC system (supply air flow rate in cfm) and the percent outside air calculated above are necessary to calculate the amount of outdoor air in cfm that is supplied. Finally, the amount of outdoor air supplied per person is calculated by dividing the total room supply air value in cfm by the total number of employees in the area served by the air handling unit of interest.

The calculated values for the ventilation rates indicate sufficient outside air flow is being provided by all air-handling units serving the two floors of interest. The flow rates ranged from a low of 19.5 cfm of outside air per person up to 29 cfm per person. These are acceptable values as compared to the ASHRAE recommended guideline.

Another important point in considering ventilation rates is the concept of "ventilation effectiveness." Ventilation effectiveness is defined by the fraction of the outdoor air delivered to the space that reaches the occupied zone (23). It is not uncommon to find some of the ventilation air bypassing the occupants (moving from supply to exhaust without fully mixing in the occupied zone); such a situation would relate to a low ventilation effectiveness factor which would reduce the efficiency of the ventilation being provided. Unfortunately, ASHRAE has not clearly described how ventilation effectiveness is to be measured. Ventilation efficiency measurements in both laboratory and field evaluations reported in recent years indicate that actual ventilation rates in buildings are typically 50 to 75% of the designed ventilation rate due to short circuiting and inadequate mixing within the occupied space (27). As a function of these findings many building designers are now revising the design conditions to provide the required air supply volume by joining the critical aspect of ventilation efficiency (effectiveness) to air exchange or outside air supply quantities.

The concept of ventilation effectiveness is of significance in this study due to the number of occupant complaints with respect to "stale" air, even though calculations indicate that the prescribed ventilation rate per ASHRAE guidelines is being provided to each zone. Thus a ventilation efficiency of less than 100% is probable due to short circuiting of the supplied air. Poor mixing of air is a common problem found when air is delivered and returned through ceiling diffusers, as was the case in this building. Another possible contributor to the complaints of stuffy air on the two floors are the use of tall furniture such as filing cabinets and acoustic screens (partitions) which may impede air circulation throughout the occupied zone. The term "occupied zone" is defined by ASHRAE as the region within an occupied space between planes 3 inches and 72 inches above the floor and more than 2 feet from the walls. Because air-handling for most office floors is designed for an open and unobstructed space, walls and partitions built to enclose work stations or meeting rooms can prevent the efficient flow of air. The use of partitions in office spaces must be compensated for by proper ventilation design parameters to adjust for the reduced efficiency of the air circulation. Partitions are important from the standpoint that most workers prefer to have the option of not being fully available to others in the office at all times. Without the use of partitions, the open office plan creates the illusion of interpersonal availability and job stress factors may be compounded by this additional concern. Thus acoustical screens and other controls must be used judiciously to modify the open office plan without resorting to full enclosure for every desk. The acoustical partition drawbacks include the lack of total privacy, a reduction in the efficiency of the overall illumination, the impediment of air circulation, and on a large floor, researchers hypothesize that the labyrinth effect that can be somewhat confusing and disheartening (31). Some of these drawbacks appear to play a role in the number of complaints generated from the second floor before renovations. The use of partitions in the older office plan (prior to the ongoing renovations) was not well organized and definitely created a maze type of environment within the space. This lack of order also contributed to maintenance problems and thus the accumulation of dirt in these areas (as was previously discussed). This lack of order and random placement of partitions has been remedied somewhat in the new office design. The partitions in the new office layout will still play a role in the lack of air circulation and mixing which must be taken into account. Partitions that clear the floor at their base to a height of 1 to 2 inches will allow for better air flow and mixing. The two days of carbon dioxide sampling revealed that the air was being mixed better on the fourth floor as opposed to the older second floor areas which suggests that the new office design provides for a better distribution of the supply air.

Standard smoke tubes, temperature and CO_2 measurements at different heights above the floor are useful techniques (9) that were engaged in the evaluation of air stratification resulting from poor mixing. Smoke sticks consist of a tube that produces a chemical, visible smoke that can be tracked as a function of air currents within the occupied space. Smoke stick tests were conducted on December 13, 1989 on both floors. These tests basically revealed very poor air distribution in the unrenovated areas of the second floor, especially within the partitions. Many employees, in an attempt to pull more air into their area, would dislodge the ceiling tiles above them. By doing so, they basically exacerbated the already poor air circulation situation since, with an open plenum return, the air would simply enter through the ceiling supply diffusers and exit through the nearest dislodged ceiling tile. This problem was compounded by the fact that many ceiling tiles were missing due to the ongoing construction on the second floor. Some of the poorest air circulation observed on the second floor (from smoke stick tests) was at a location where adequate mixing of the air is perhaps needed the most -- at the copier space (two large copiers placed side by side in this space). There were no return vents close to this area to enable the exhausting of the copier fumes and prevent buildup of contaminants. Smoke stick tests conducted on the fourth floor generally revealed enhanced air distribution as compared to the second floor, but still could be improved upon. Partitions impede the air mixing to some extent, yet the more ordered arrangement of the partitions leaves more open space for the air to infiltrate.

Carbon dioxide and temperature measurements were taken at varying heights above the floor on March 8, 1990 to examine variations in measurements as a function of air stratification. Two observations with respect to the data are of interest: The inordinately high CO_2 readings recorded on both floors, and the higher than normal temperatures recorded. On this day of tests CO_2 readings on both floors averaged 1100 ppm while the temperature ranged from 78-80°F. Both of these problems existed as a function of chilled water problems. According to building maintenance, chilled water, typically supplied to the building at a temperature of 42°F, is used to temper the air when outside temperatures exceed 55°F. On this given day, the outdoor temperature was 75°F and the chilled water was being used for cooling purposes. Investigators were informed that building engineers were receiving chilled water at an elevated temperature of 52°F, instead of the normal 42°F temperature. Due to the higher chilled water temperature, and thus its reduced cooling and dehumidification capabilities, the air supplied to the occupied zone was being provided at a higher temperature than normal accompanied by a much higher humidity content. The relative humidity levels recorded on the second and fourth floors ranged from 59-67%. Because of the chilled water problem, the amount of outside air being introduced into the HVAC system was at an absolute minimum, which is reflected in the high CO_2 values recorded. As temperatures within the occupied space would rise (as a function of increased chilled water temperature), building engineers would cut off all outdoor air supply so as to increase the capacity of the equipment. The problem with the chilled water was not a new one as was reflected on the initial walkthrough, and definitely should be resolved such that engineers can ensure the provision of adequate outside air at all times the building is occupied.

The CO_2 measurements recorded at different heights on the second floor exhibited some degree of variance due to partial air stratification occurring. The differences in readings taken at 4 inches (floor level) and 67 inches (breathing level) above the floor ranged from a differential of 59 ppm (between the two heights) up to 178 ppm. Carbon dioxide measurements from the fourth floor revealed less discrepancy between the 4-inch and 67-inch height values. The differences in fourth floor values ranged from a differential of 0 ppm (between the two heights) up to 29 ppm. These measurements indicate that the air mixing on the fourth floor was somewhat improved as compared to the second floor.

Temperature measurements were taken at the 4-inch and 67-inch heights to ascertain the vertical difference in air temperatures between the floor and head level. ASHRAE's Standard 55-1981 "Thermal Environment Conditions for Human Occupancy" recommends that the vertical temperature gradient shall not exceed 5°F at 4-inch and 67-inch levels (32). The data from the two floors indicate that the observed vertical temperature gradients are acceptable, although somewhat elevated as previously discussed due to the chilled water problems.

One final note to cover with respect to the HVAC analysis pertains to the significance of properly balanced air-handling systems to ensure an adequate and uniform distribution of the supply air throughout the occupied space served by each air-handler. All too often, the system is inadequately balanced or not balanced at all. Improper balancing of the air system contributed to air quality problems on the second floor. Building engineers admitted on more than one occasion that the system had been unbalanced for some time on the second floor due to the construction and renovations. They also informed us that the system was more set and balanced on the renovated fourth floor which may account for the somewhat improved conditions reflected in the air quality measurements.

TEMPERATURE AND RELATIVE HUMIDITY MEASUREMENTS

The primary complaint of "stuffy air" listed by the majority of questionnaire respondents has been discussed in some detail. The second most common grievance with respect to the work environment was that of thermal discomfort experienced by employees; specifically the temperature being too hot or too cold within the occupied space. Temperature and relative humidity measurements were taken periodically throughout the work day on two separate occasions, September 14 and December 11, 1989, to evaluate the termal parameters and fluctuations that may occur.

In general, a person's comfort is affected by: temperature, relative humidity, air diffusion and supply of outdoor air. The standards for maintaining a certain acceptable level of comfort and occupational activity range from 68°F to 79°F, taking into account the clothing and the relative humidity. However, there are recent findings that indicate the temperature should be kept in the lower part of the comfort range. Researchers have observed a statistical relationship between elevated room temperatures above 75°F and the appearance of sick building syndrome symptoms. A reduction in work capacity has also been demonstrated in studies of occupants in work environments above this temperature (33,34). Another important consideration is that higher indoor temperatures will accelerate offgassing processes from building materials which contribute to volatile organics accumulating in the air.

Guidelines have been established by ASHRAE (Standard 55-1981) in order to provide guidance in designing and maintaining acceptable indoor thermal environments. The aim of these requirements is to define a thermal environment which is acceptable for at least 80% of the occupants.

On the first day of testing, September 14, 1989, the relative humidity averaged around 50% and temperatures ranged from 71°F up to 78°F depending on location. These temperatures are reasonable for this time of year. Temperatures were generally slightly higher on the second floor as compared to the fourth floor. On the second day of testing, December 11, 1989, the relative humidity averaged around 20-30% and temperatures ranged from

69-76°F depending on location, which are also reasonable values. Overall temperatures were again higher on the second floor as compared to the fourth floor. Tracking the temperatures throughout the course of the day, a rise in temperature generally occurs with peak values recorded in mid to late afternoon and lowest values before and after people occupied the building. These trends are not uncommon and can partially be attributed to human activity in an occupied work space during the course of the day.

There is no universal agreement on what constitutes the ideal range of relative humidity. It is known that high values (above 70%), particularly associated with elevated temperatures, are uncomfortable and health may be threatened, at least through the development of surface condensation, mold growth, and enhanced microbial activity (35). Very low relative humidity has been suggested to cause drying of the mucous membranes and skin and cause discomfort for people wearing contact lenses. However, research has been conducted indicating that in 78-hour exposures to dry clean air no signs nor symptoms were found among the occupants; even in people with high metabolic rates (36). Thus, some scientists question whether humidification systems are necessary, at least in the cases where relative humidity is already in an acceptable range. ASHRAE's defined "comfort zone" recommends relative humidity levels between 20 to 60% with a recommended design guideline of 40% (32). The humidity levels recorded on both dates of testing were acceptable on the whole considering the seasonal conditions of each test period.

It is important to point out that while thermal conditions on these two days of testing reflect acceptable values, it cannot be stated that these two days are representative of the entire work year. Indeed, as was reported previously with respect to conditions within the occupied space on March 8, 1990, there will be excursions from what is considered acceptable. These "excursions" must be eliminated whenever possible to allow for acceptable IAQ on a year-round basis. Balancing the air-handling system on a periodic basis and ensuring that the chilled water is at the design temperature for proper cooling and dehumidification should minimize these "excursions" from recommended thermal and ventilation guidelines.

LIGHTING

Where work space is used mainly to support specific visual tasks, as in offices, the quantity and quality of lighting can have a major influence on the efficiency with which tasks are carried out and on the comfort and well-being of the worker. According to the American Industrial Hygiene Association, "there is no evidence that poor lighting will create eye defects; however it has been definitely proven that people perform more efficiently when the environment is comfortable, pleasant, and has sufficient illumination for easy visual perception" (37).

Recommended minimum in-service illumination level for office desks and office equipment is 60 foot-candles (37). High levels of constant overhead lighting are not really necessary, especially if task lighting at the desk is available. With switchable task lighting provided for every occupant, the overhead or background lighting in an open office space can be as low as 15 to 25 foot-candles (30).

General background illumination on the fourth floor ranged from 18 to 24 foot-candles and was generally very uniform throughout the space. These levels in conjunction with the task lighting provided at each work space were much improved as compared to the second floor and are within recommended guidelines as discussed. The lighting system on the fourth floor, in conjunction with the ordered partitions, is satisfactory from the standpoint that it enables occupants to adjust as many aspects of their lighting conditions as possible without having a negative impact on the other workers in a space.

PHOTOCOPIERS AND OFFICE EQUIPMENT

Recent research has indicated that while building materials and furnishings are contributors to airborne levels of volatile organic compounds (VOC's), occupant activities can add significantly to the total VOC concentration. Specifically, photocopiers and plotters are major VOC sources that must be considered in a thorough office investigation (31).

A representative area on the second floor marks the location of two large photocopier units that have been discussed earlier related to the poor ventilation in this area. Ingredients of the dry ink used for the operation of the copiers consisted of styrene, butadiene, and ammonia (ammonium salts) which may become airborne with copier use. A similar set of photocopiers are present on the fourth floor located within a mail room. This area was ventilated much better than the second floor area, having two supply ducts and two returns within this space. Monitoring for ammonia, styrene and butadiene was conducted on March 8, 1990 to determine levels in the photocopier area on each floor. The readings were taken at a time of increased photocopier use, between 2:00 and 4:00 pm in the afternoon. OSHA time weighted averages for ammonia, butadiene and styrene are 35 ppm, 1000 ppm and 50 ppm respectively. All recorded values on this given day of sampling were well below these guidelines and do not present reason for concern. The judicious location of such equipment within the office space in conjunction with an adequate air distribution system should minimize occupant complaints. The provision of direct exhaust of copier fumes and dust is ideal for such areas.

OTHER CONCERNS

There are many other constituents of the office work space that contributed to the overall buildup of contaminants adversely affecting the IAQ. Secretarial whiteout (contributes trichlorethane), carbonless copy paper (contributes formaldehyde), printers and shredders (contribute dust and particulates), cleaning products, etc. must all be considered as contributors to contaminant buildup within the investigated space. The provision of an adequate air supply (with effective distribution throughout the space) in conjunction with an efficient routine maintenance and cleaning schedule should minimize the health hazards that these contaminants may present.

Because of the multitude of VOC's associated with new carpeting and the expense involved, air testing is not recommended. Typically, problems with carpets are identifiable by the presence of carpeting odor and/or upper respiratory irritation, with the onset of symptoms occurring within days of installation (27). Because of the lack of evidence of carpet-related problems at the building site (no strong carpet-related odors, or complaints with respect to the carpets after installation), an indepth analysis of the air quality as a function of carpet fumes was not conducted. However, the carpet adhesive used for the renovation was researched to determine possible health related problems. Due to the low concentrations of any hazardous ingredient in the adhesive and the low health hazard ratings of the chemicals involved, the carpet and adhesives should present minimal health hazards if proper ventilation is applied during installation.

RECOMMENDATIONS AND CONCLUSIONS

A. Inspection of the filtration system in the air handling units revealed several shortcomings. Loose and deteriorating seals on doors and access panels should be cleanly removed and replaced with new seals. Filter holding devices should be retrofitted so as to ensure seal integrity in the filter bank. A good preventative maintenance program should be effected that includes proper filter maintenance. Properly installed and operating manometers across all filter banks in conjunction with periodic visual inspections should be included in the program. Proper filtration can well be justified in terms of reduced worker complaints, enhanced productivity, energy conservation and lower maintenance costs.

B. As renovations continue, care should be taken to ensure that occupants of the building are not exposed to elevated levels of particulates and volatile organics. If possible, directly exhaust the work areas to outdoors and isolate the occupied areas as best possible during renovations. Immediately after work is completed, aggressive ventilation combined with possible use of bakeout procedures should be considered to accelerate the chemical offgassing of newly installed materials such that upon occupant reentry, occupant exposure is minimized.

C. Certify all air-handling systems are balanced to ensure that correct amounts of air are delivered and returned. Outside air minimum should comply with ASHRAE's recommended guide of 20 cfm outside air per person. This aspect of the HVAC system is critical due to the amount of equipment, furniture and partitions on the floors that impede the circulation of air to the people, and thus reduces the ventilation efficiency. Air-handling systems should be rebalanced on a periodic basis, depending on changes in occupancy and work group relocations. The partitions and equipment in the renovated office layout will, although improved over the second floor layout, still play a role in impeding air circulation and promoting short circuiting effects. Thus, due to the lowered ventilation efficiency, HVAC design parameters should be adjusted to ensure that an adequate amount of fresh air reaches the occupied zone.

D. The problem with the provision of adequate chilled water at the correct temperature for the building must be resolved to ensure that supply air is properly tempered and dehumidified before being delivered to the work space. This should ensure office air temperatures being within ASHRAE comfort zone guidelines (approximately 73-78°F during summer and 68-75°F during the winter), and acceptable relative humidity levels between 20 and 60%. Humidifier systems if used during winter, but not necessary during summer, must be cleaned on a periodic basis to prevent microbial activity. Humidifiers should use a "clean steam" moisture source. If raw steam from a central boiler is used, toxic corrosion inhibitors should not be present in the steam delivered to the dehumidifying device. It is also important to note that when chilled water is provided at too high a temperature, the air is not properly tempered or dehumidified. These problems are compounded as building engineers reduce the supply of outside air which simply exacerbates the situation. Thus the provision of chilled water at a proper temperature must be ensured to avoid "periods" of poor IAQ within the occupied space.

E. Check that all ceiling tiles are in place to avoid short circuiting of the supply air.

F. Measured levels of formaldehyde and carbon monoxide as a function of cigarette smoke were well below concentrations of concern for an office space. These constituents represent only 2 of the over 4700 compounds included in both the gaseous chemical and particulate matter of cigarette smoke. While the individual chemical exposures will inevitably be below documented levels of concern, complaints with respect to passive smoke will persist as long as the smoking policy remains as it presently stands. Separation of smokers and nonsmokers within the same air space reduces, but does not eliminate, exposure of nonsmokers to ETS. Recirculation of tobacco smoke gas constituents in the air-handing system is an important source of exposure of nonsmokers to ETS in office buildings. The EPA has concluded in its 1989 Report to Congress on Indoor Air Quality, "ETS is best controlled by smoking bans, or by restricting smoking to rooms that are depressurized relative to the nonsmoking part of the building and directly exhausted to the outside" (24).

G. Ensure, in times of heavy precipitation, that standing water accumulated in front of the outdoor air intakes does not produce microbial activity, i.e. fungi, mold, mildew, etc., that may be aerosolized and drawn into the building. A periodic check to note any possible mold growth should be undertaken in this area to provide for proper cleaning if required.

H. Routine cleaning operations combined with a fastidious maintenance program and the provision of an adequate supply of fresh air should reduce occupant complaints with respect to a "stuffy" and/or "dirty" work environment. Adequate return and supply vents should be located in the areas of heaviest photocopier use to ensure adequate air circulation within this space. Ideally, the direct exhaust of air in these areas would eliminate most photocopier complaints.

I. Dust and particulates are bound to be generated in the building due to the high level of paper use and movement. By following the previously cited filter recommendations, in conjunction with an attempt to maintain the building's humidity at 40% to reduce the amount of airborne particulate, a higher degree of IAQ should be achieved.

Overall, tests indicated the quality of the air provided to the fourth floor as compared to the unrenovated areas of the second floor showed a marked improvement. The improved fourth floor design, lighting and enhanced air circulation, combined with the implementation of these recommendations, should result in reduced air quality complaints from occupants and the provision of a healthier, more productive work environment.

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TABLE 1. CARBON MONOXIDE SAMPLING

Date of Sampling: 09/14/89

All concentrations of carbon monoxide expressed as parts per million (ppm)

TIME	Second Floor Locations							
	2-A	2-B	2-C	2-D	2-E	2-F	2-G	2-H
8:35AM	4.1 ppm	4.3 ppm	4.3 ppm	4.4 ppm	4.5 ppm	4.3 ppm	4.9 ppm	4.6 ppm
1:45PM	3.7 ppm	3.8 ppm	3.7 ppm	3.8 ppm	4.0 ppm	3.6 ppm	4.3 ppm	3.9 ppm
5:30PM	5.7 ppm	5.8 ppm	6.0 ppm	6.0 ppm	5.9 ppm	5.4 ppm	5.8 ppm	5.6 ppm
9:15PM	3.8 ppm	3.0 ppm	3.1 ppm	3.2 ppm	3.0 ppm	3.2 ppm	3.0 ppm	3.2 ppm

TIME	Fourth Floor Locations							OUTSIDE CONCENTRATIONS
	4-A	4-B	4-C	4-D	4-E	4-F	4-G	
8:55AM	3.4 ppm	3.2 ppm	3.4 ppm	3.3 ppm	3.3 ppm	3.3 ppm	3.2 ppm	2.8 ppm
2:00PM	3.5 ppm	3.0 ppm	3.8 ppm	2.9 ppm	3.4 ppm	3.8 ppm	3.0 ppm	3.4 ppm
5:45PM	5.3 ppm	5.2 ppm	5.6 ppm	5.5 ppm	5.3 ppm	5.5 ppm	5.5 ppm	5.3 ppm
9:30PM	2.9 ppm	3.0 ppm	2.5 ppm	2.7 ppm	3.0 ppm	3.0 ppm	2.8 ppm	2.8 ppm

TABLE 2. CARBON DIOXIDE SAMPLING

Date of Sampling: 09/14/89; Outdoor T = 16°C = 61°F

All concentrations of carbon dioxide expressed as parts per million (ppm).
Outdoor CO_2 concentration = 350 ppm.
(NOTE: All indoor readings taken at a level of five feet off of the floor.)

TIME	Second Floor Locations							
	2-A	2-B	2-C	2-D	2-E	2-F	2-G	2-H
7:30AM	550 ppm	540 ppm	554 ppm	511 ppm	568 ppm	556 ppm	546 ppm	673 ppm
10:00AM	590 ppm	715 ppm	646 ppm	665 ppm	700 ppm	690 ppm	695 ppm	734 ppm
1:00PM	647 ppm	619 ppm	660 ppm	660 ppm	748 ppm	690 ppm	754 ppm	803 ppm
3:00PM	610 ppm	643 ppm	705 ppm	684 ppm	743 ppm	720 ppm	809 ppm	890 ppm
4:45PM	722 ppm	756 ppm	704 ppm	709 ppm	690 ppm	712 ppm	658 ppm	723 ppm
8:40PM	589 ppm	626 ppm	580 ppm	574 ppm	599 ppm	576 ppm	555 ppm	584 ppm

TIME	Fourth Floor Locations						
	4-A	4-B	4-C	4-D	4-E	4-F	4-G
7:45AM	523 ppm	509 ppm	484 ppm	573 ppm	533 ppm	635 ppm	524 ppm
10:15AM	581 ppm	580 ppm	612 ppm	626 ppm	639 ppm	590 ppm	681 ppm
1:20PM	690 ppm	637 ppm	630 ppm	596 ppm	591 ppm	584 ppm	644 ppm
3:15PM	587 ppm	611 ppm	608 ppm	756 ppm	692 ppm	720 ppm	634 ppm
5:15PM	652 ppm	629 ppm	639 ppm	583 ppm	584 ppm	597 ppm	594 ppm
8:55PM	564 ppm	557 ppm	560 ppm	542 ppm	521 ppm	576 ppm	532 ppm